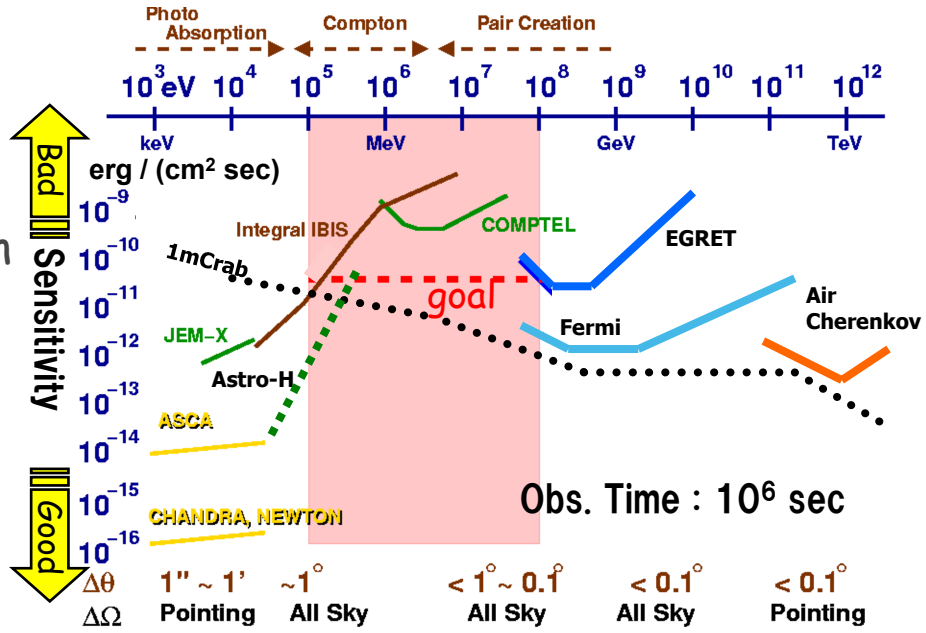
μ-PIC and its applications

A. Takada (Kyoto University)

- Our motivation
- μ-PIC and MeV gamma-ray telescope
- μ-PIC applications
- New type μ-PIC

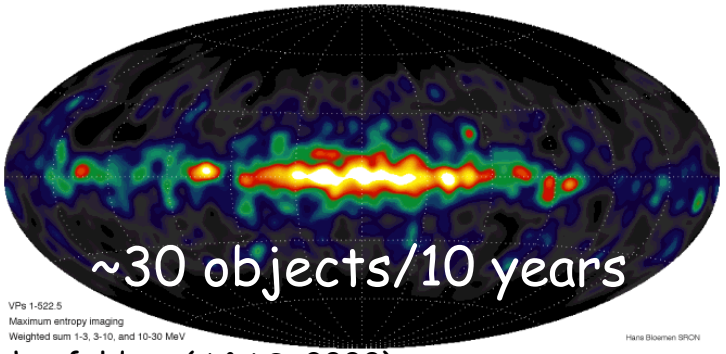
MeV Astronomy

- Nucleosynthesis
  - SNR : Radio-isotopes
  - Galactic plane : ^{26}Al • Annihilation
- Particle acceleration
  - Jet (AGN) : Synchrotron
    - + Inverse Compton
- Strong gravitational potential
  - Black hole : accretion disk, π^0
- Etc.
  - Gamma-ray Pulsar, solar flare



MeV sky map

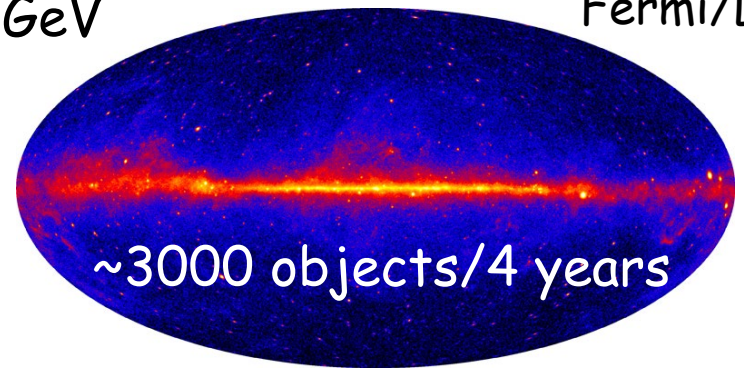
1-30 MeV CGRO/COMPTEL



V. Schönfelder+ (A&AS, 2000)

GeV sky map

> 1 GeV Fermi/LAT

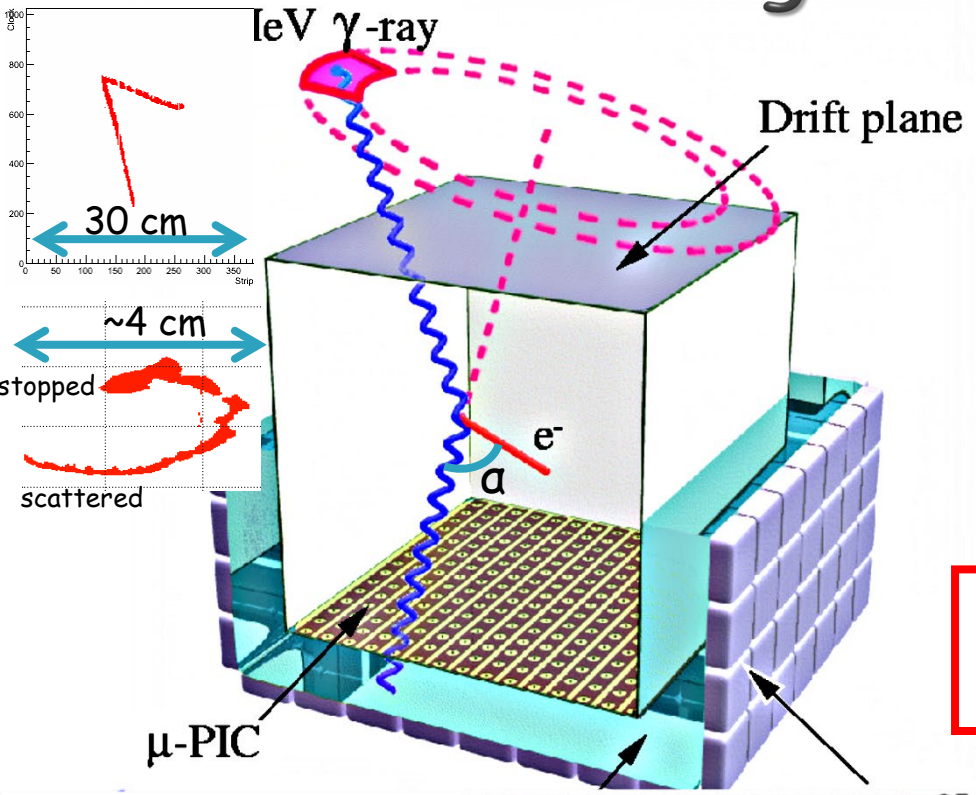


F. Acero+ (ApJS, 2015)

Requirements for the next-generation detectors are …

- Wide-band detection
- Large Field of View
- Sharp Point Spread Function

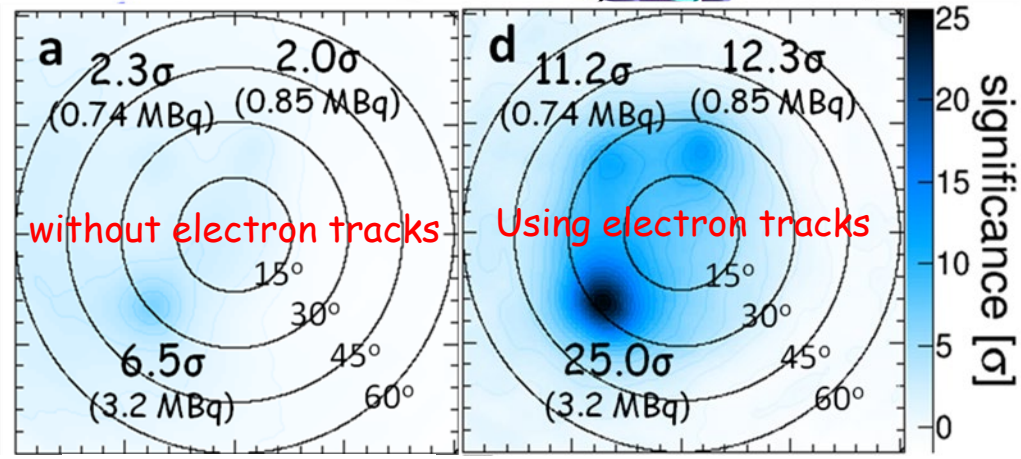
Electron-Tracking Compton Camera (ETCC)



- Gaseous TPC : Tracker
  track and energy
  of recoil electron
- Scintillator : Absorber
  position and energy
  of scattered gamma ray

Reconstruct Compton scattering event by event

- 1 photon ⇒ direction + energy
- Well-define PSF
- Large FOV (~3str)
- Simple structure
- Compton Kinematical test with angle α
- Particle identify with dE/dx
- No VETO & shield around ETCC

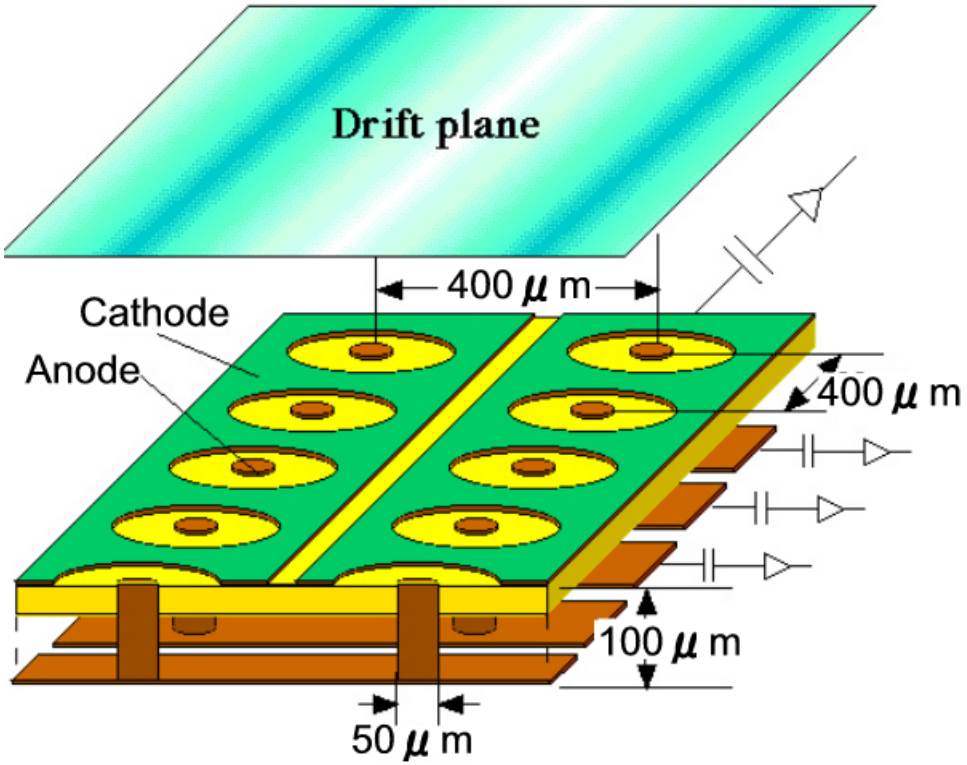


^{137}Cs (662 keV) x 3

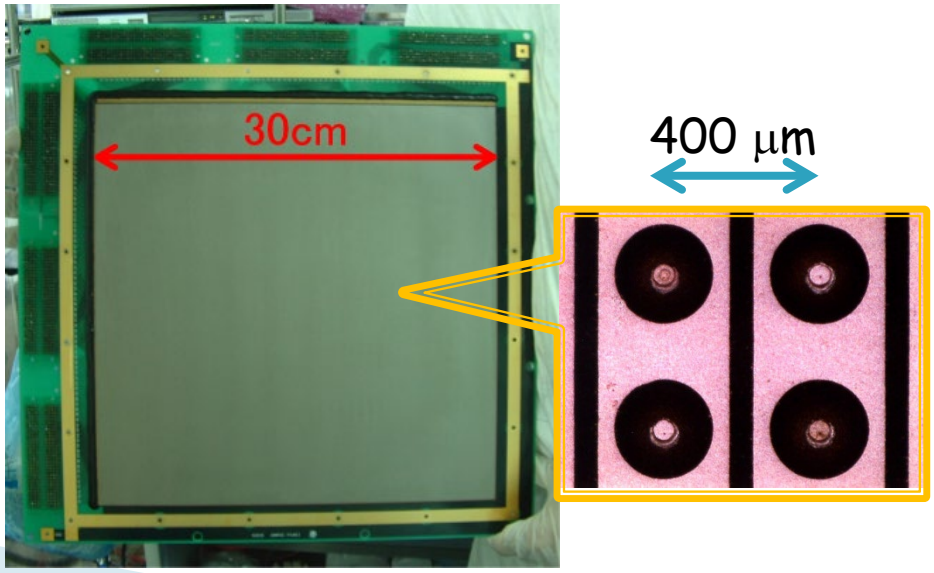
T. Tanimori+, ApJ (2015)

Gaseous Electron Tracker

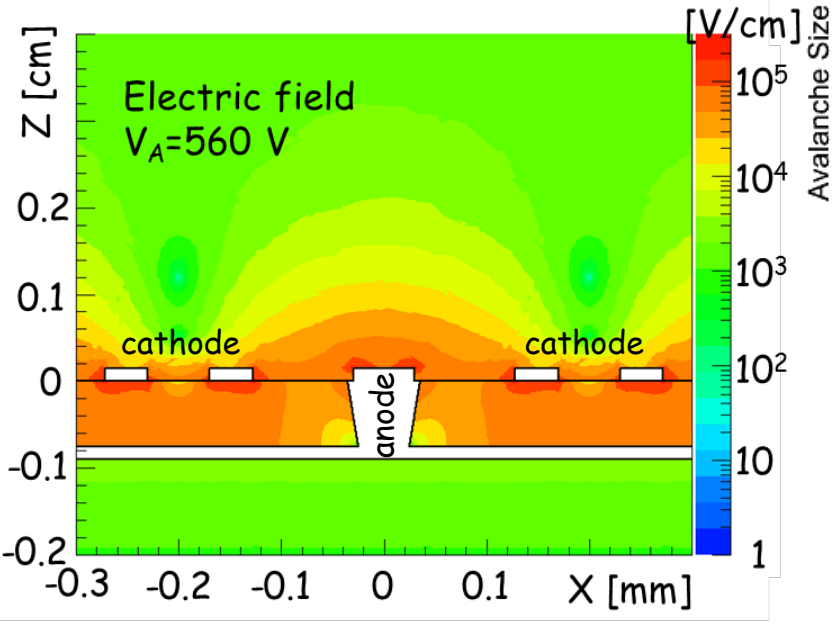
Micro Pixel Chamber (μ-PIC)

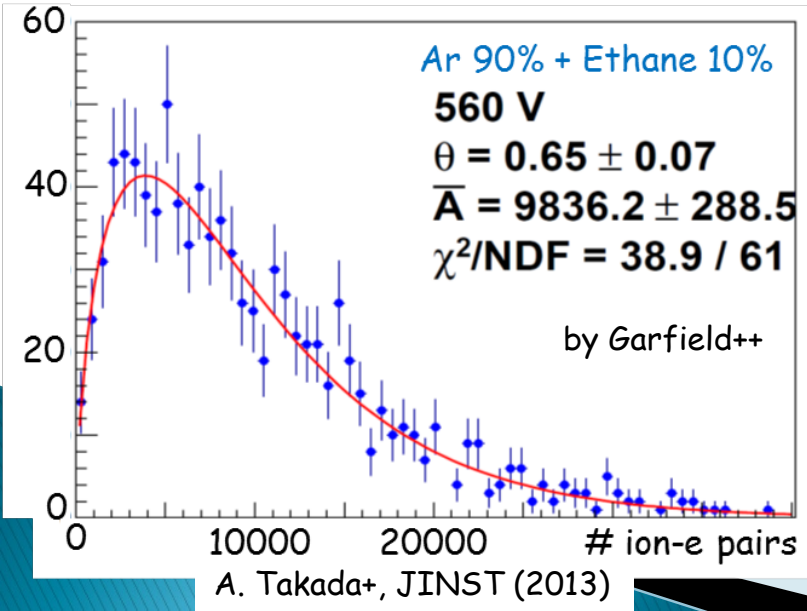


- 2D gaseous imaging detector
- by Print Circuit Board technology
- Each pixel works
  as like a proportional counter
- Large detection area :
  10×10 cm² and 30×30 cm²
- High gas gain : max ~15000
- Fine position resolution : RMS ~120 μm
- Good gain uniformity
- Stable operation over several months
  with the gain of ~6000

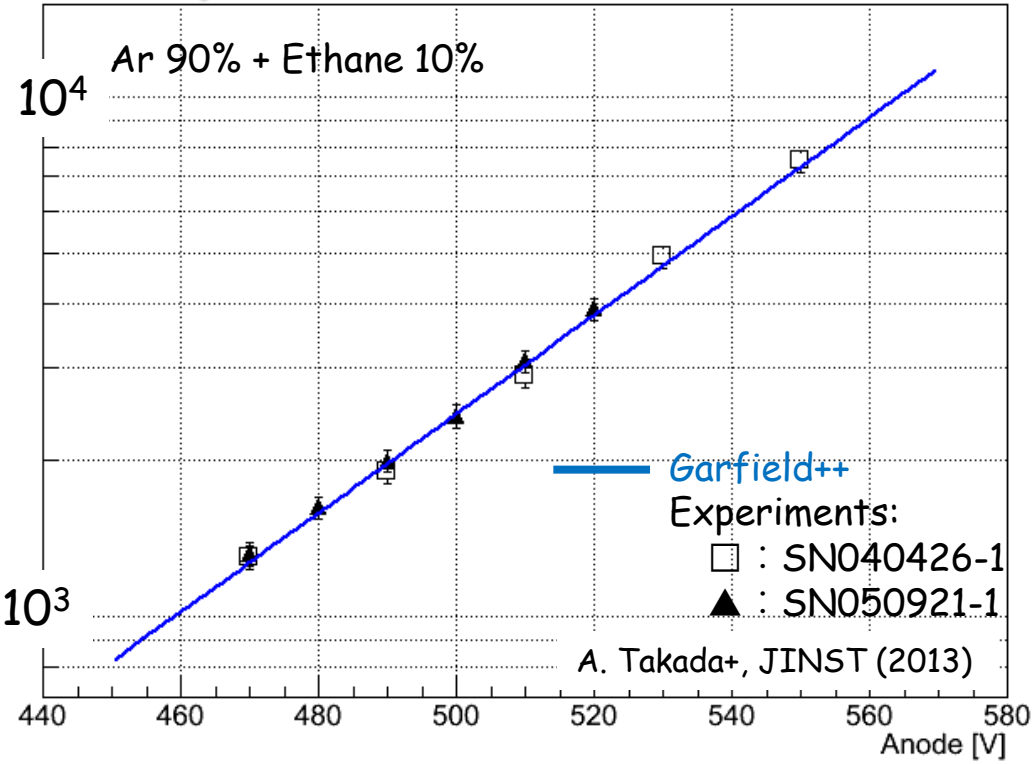


Gas avalanche in μ-PIC





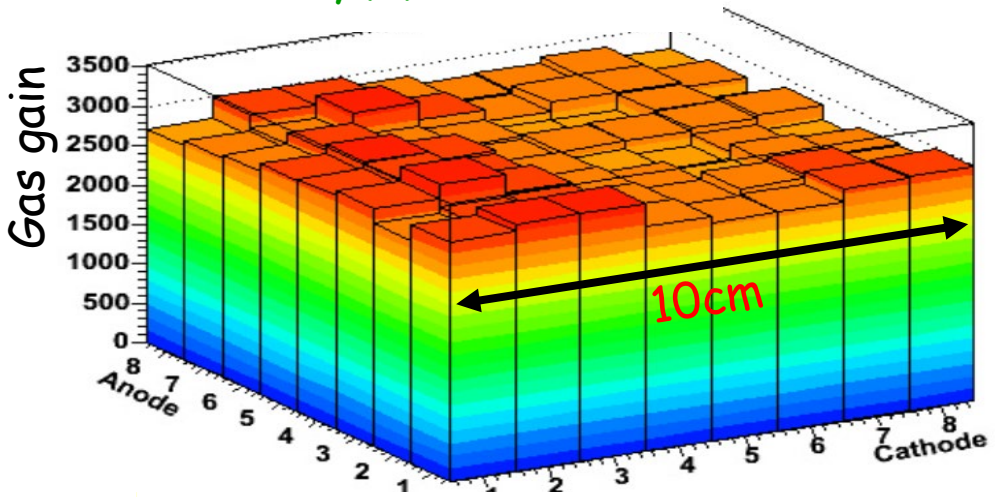
A. Takada+, JINST (2013)



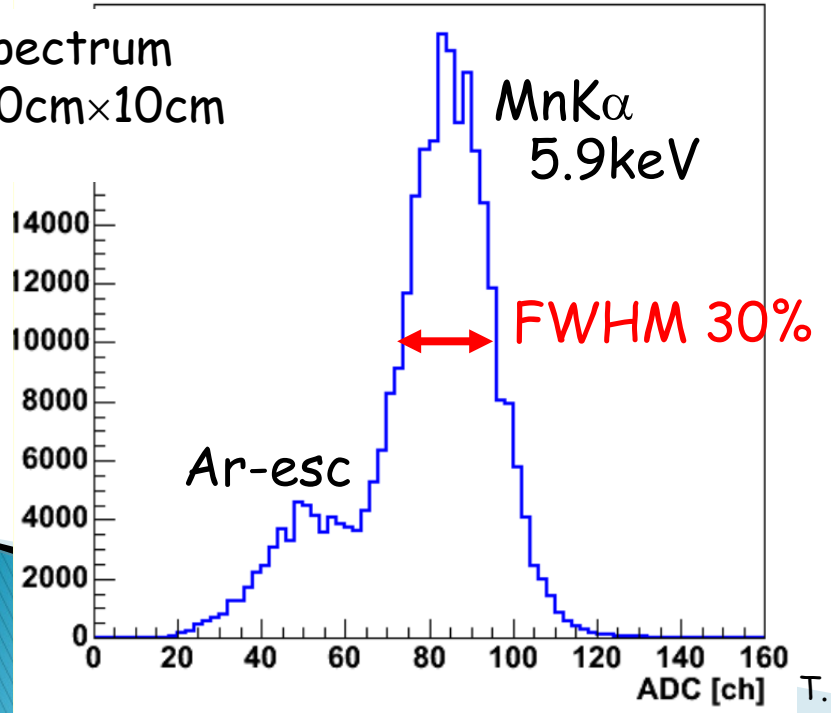
- Strong electric field near anodes
  - -> Avalanche occurs only near anodes
- Single electron spectrum
  - -> well fit by Polya-distribution
- Gas gain
  - -> Experiment data are well consistent with simulation.

μ-PIC as an X-ray detector

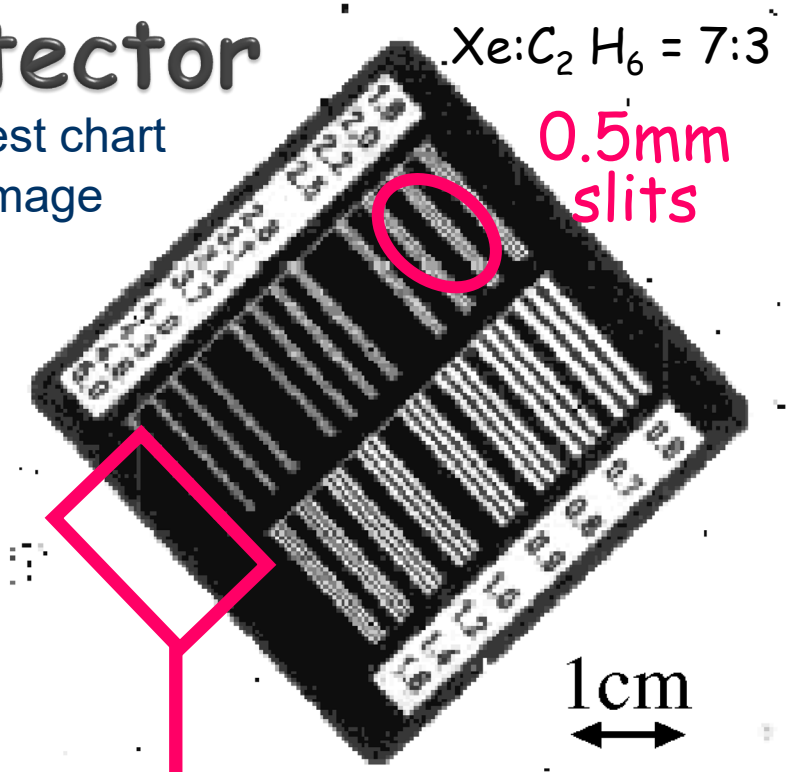
Gain uniformity(σ) 4.5%



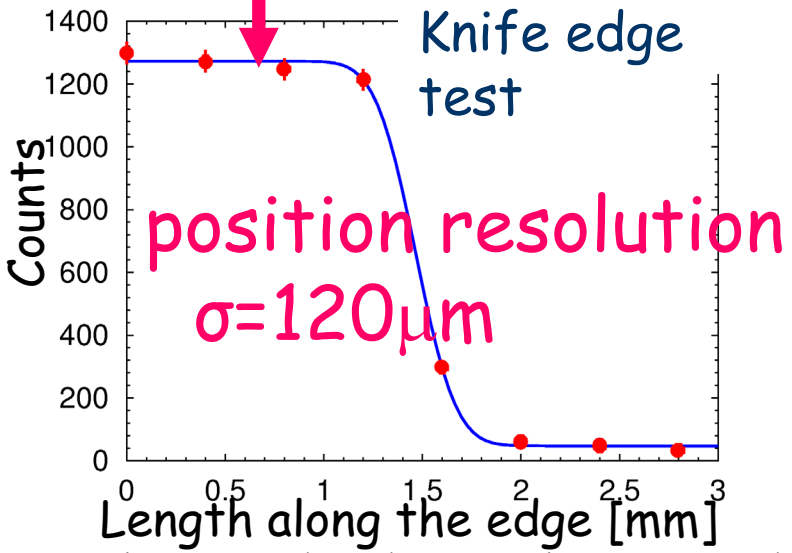
^{55}Fe spectrum
@ 10cm×10cm



Test chart image



Knife edge test



position resolution
σ=120μm

T. Nagayoshi+, NIM A (2004), A. Takeda+, IEEE TNS (2004)

A. Takada+, ApJ, 733(2011), 13

1st balloon experiment (SMILE-I)

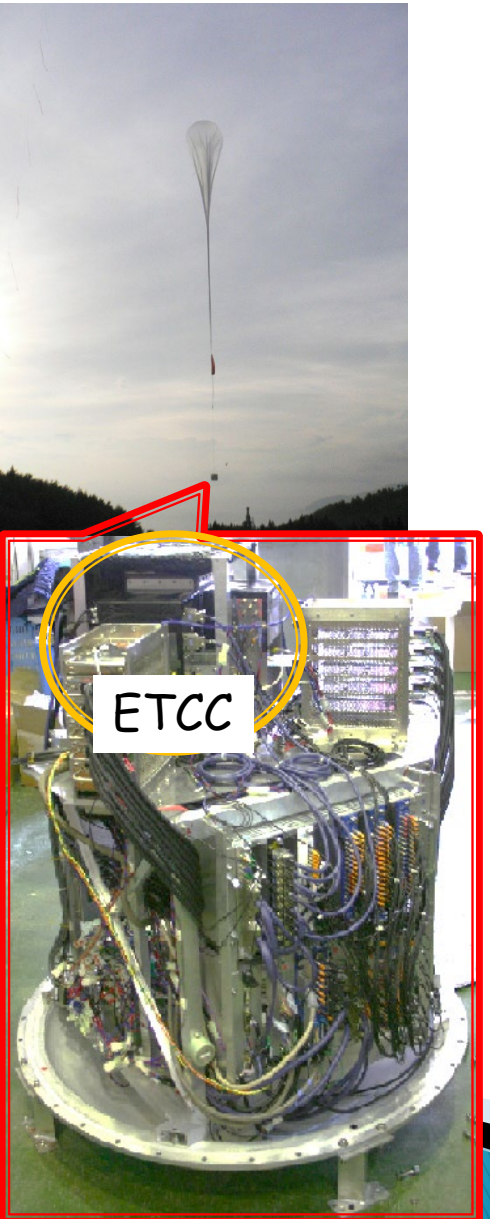
Sub-MeV gamma-ray imaging Loaded-on-balloon Experiment

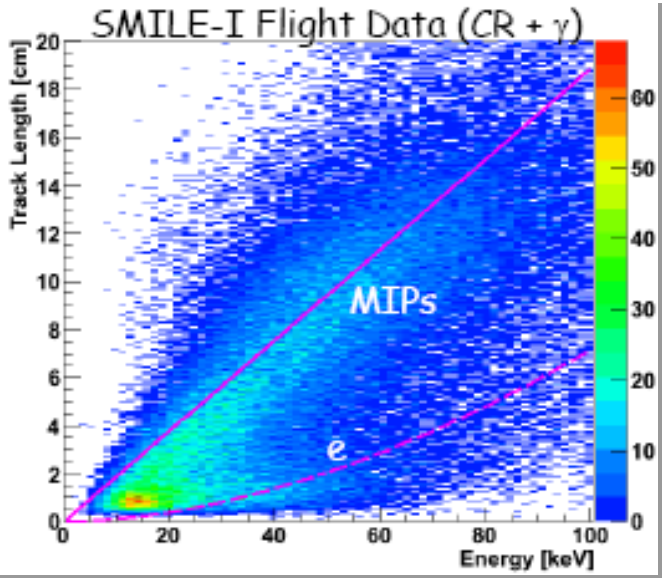
Launched on Sep. 1, 2006 @ Sanriku (ISAS/JAXA)

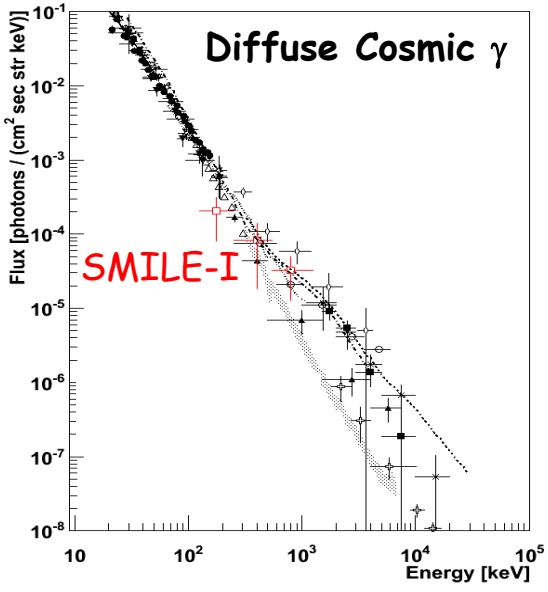
- Test flight using $(10\ \mathrm{cm})^3$ ETCC
- Measure diffuse cosmic and atmospheric gamma ray
  0.1 – 1 MeV, @ 35 km, 3 hours

Measured : 420 events
Simulation : ~400 events (cosmic + atmospheric)

Compton kinematic test and Particle identify provided low-background observation.







ETCC for 2nd balloon experiment

SMILE-II

Target: Crab nebula

5σ detection (40 km, several hours)

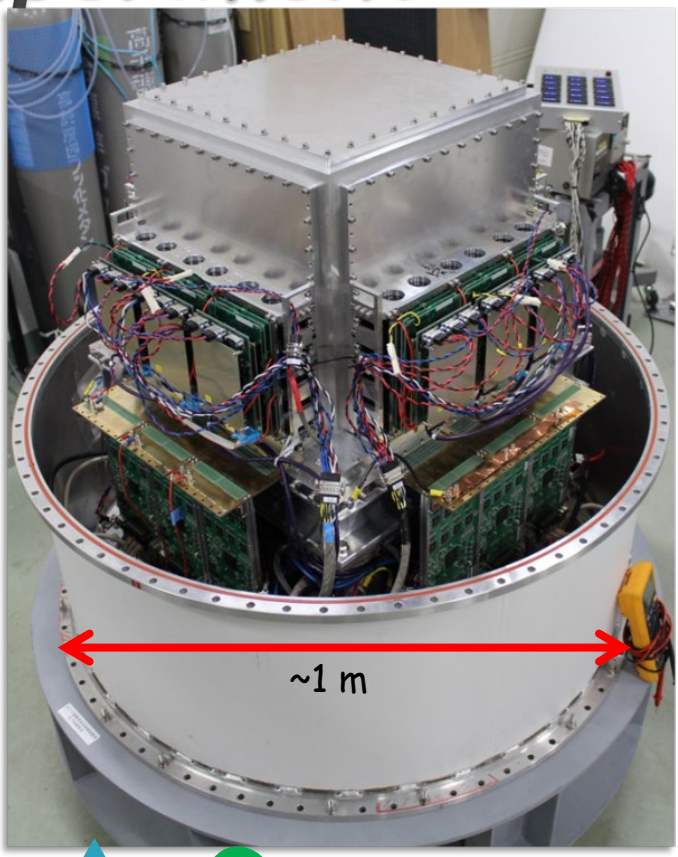
Requirements

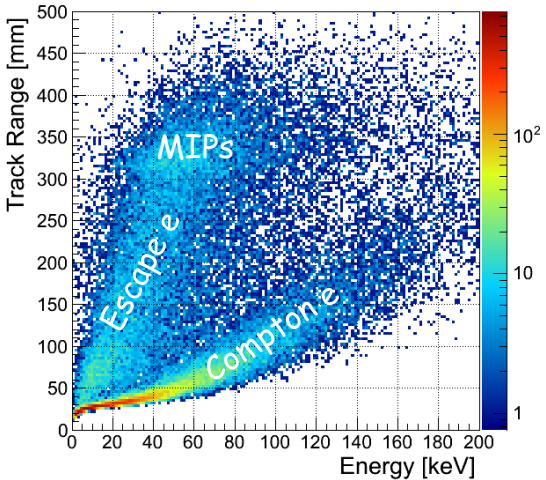
Effective area	:	> 0.5 cm² (300 keV)
Angular resolution	:	< 10° (600 keV)
Sensitivity	:	×100 SMILE-I

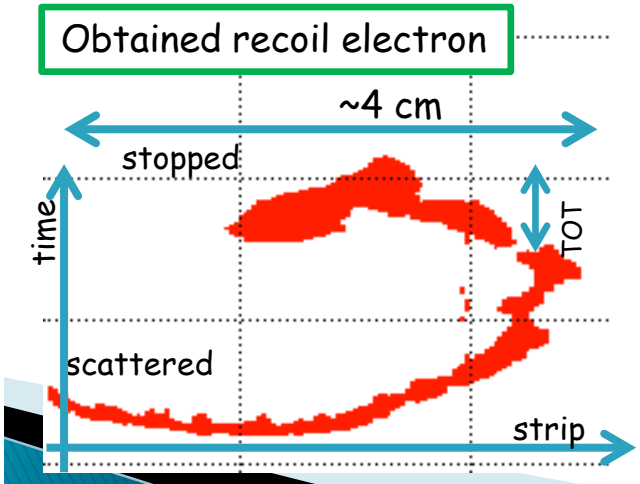
Improvements for SMILE-II

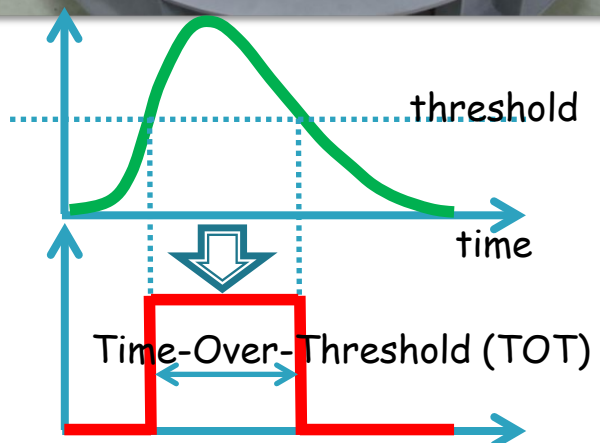
- 30 cm cube tracker ×√10
- Updating of data acquisition system ×√10
- Improvement of imaging ability ×10

Sensitivity will reach to (×100 SMILE-I) !

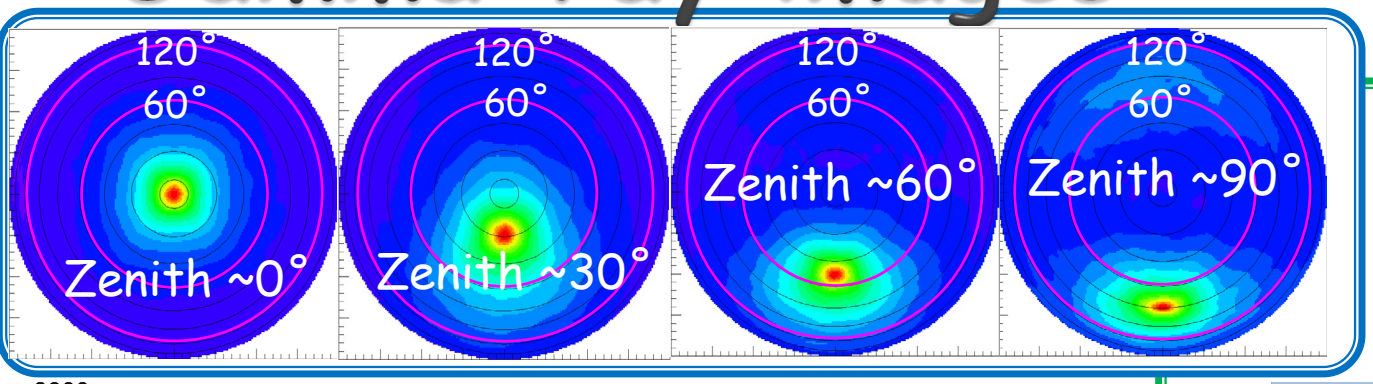


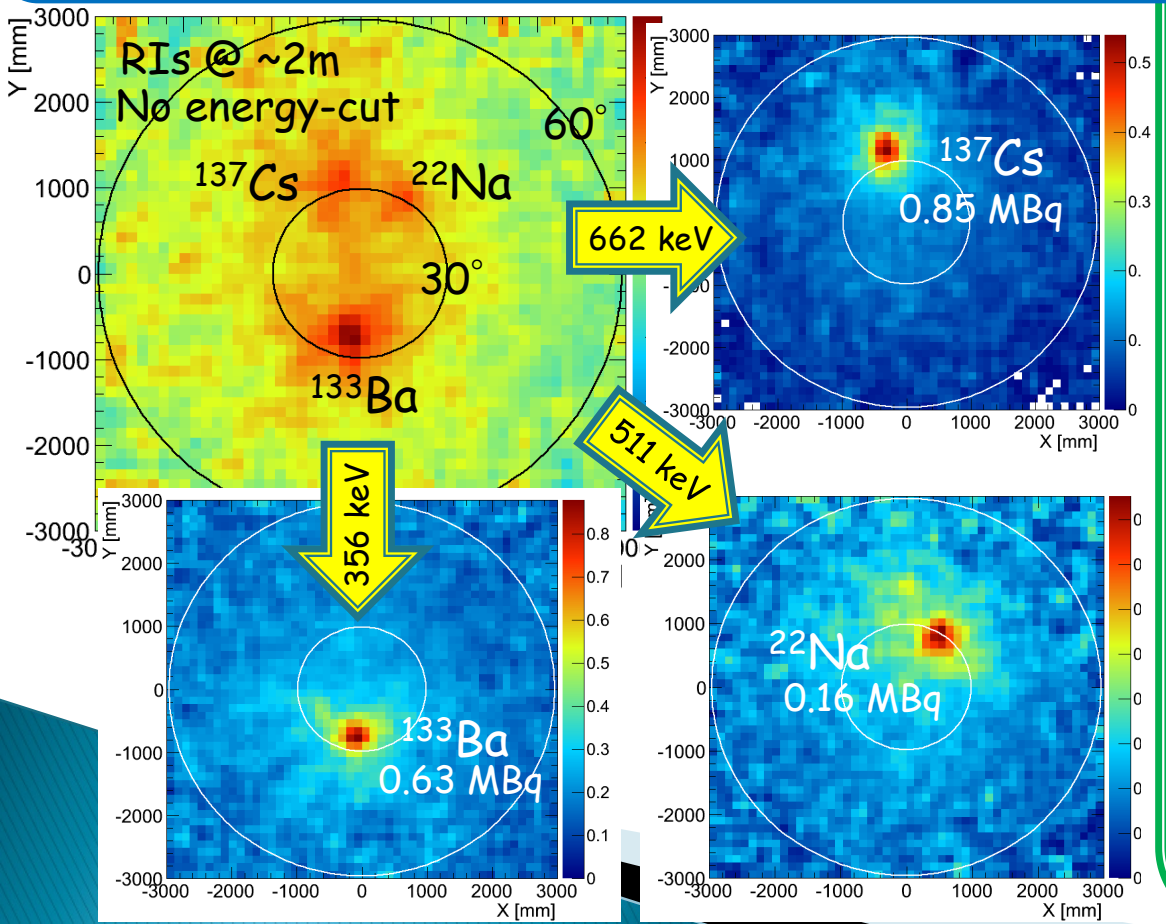


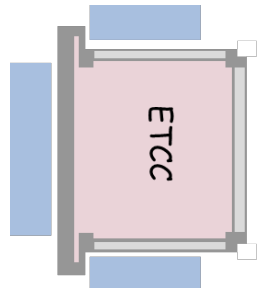




Gamma-ray images

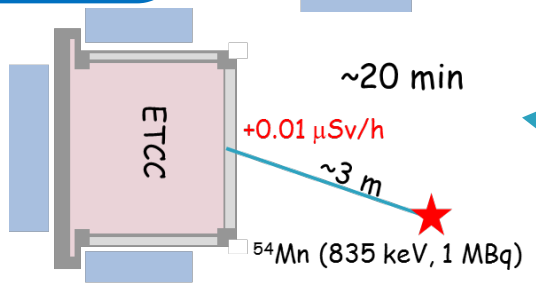


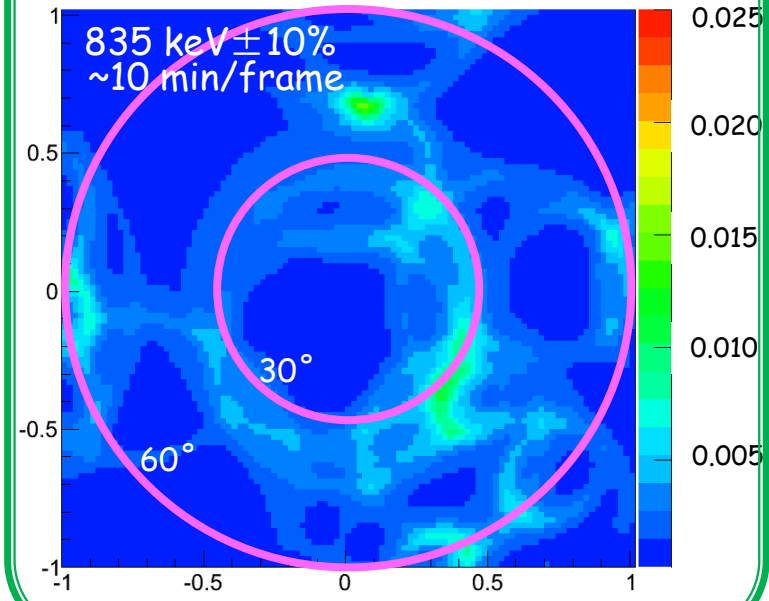




~3 hours

No source





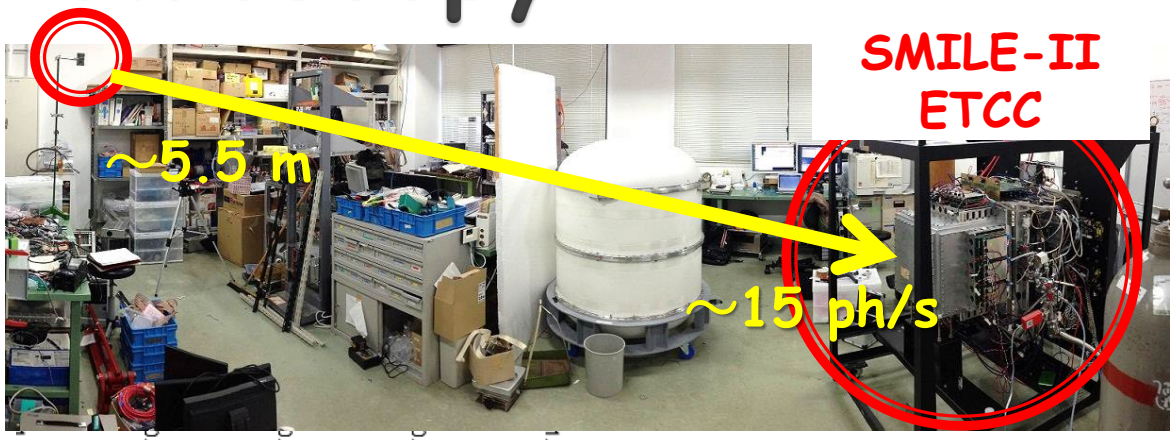
Imaging spectroscopy

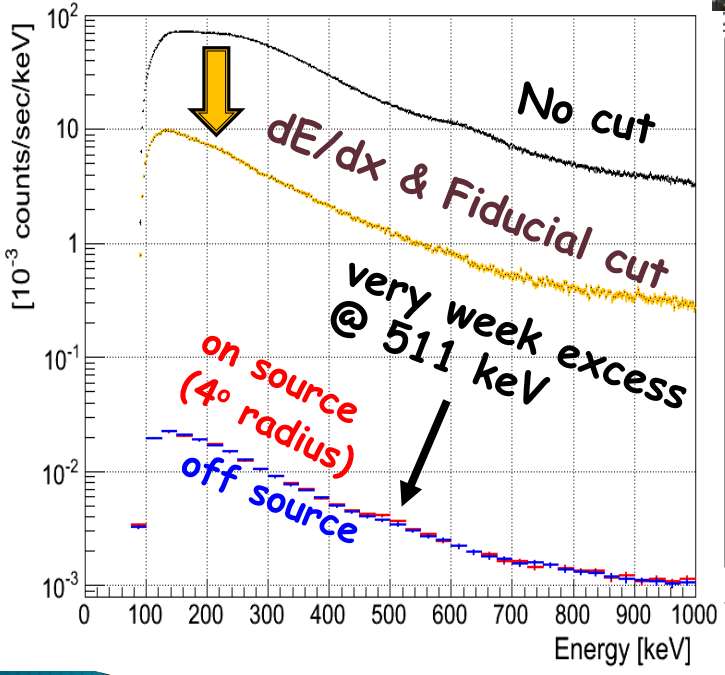
T. Tanimori+, ApJ 2015

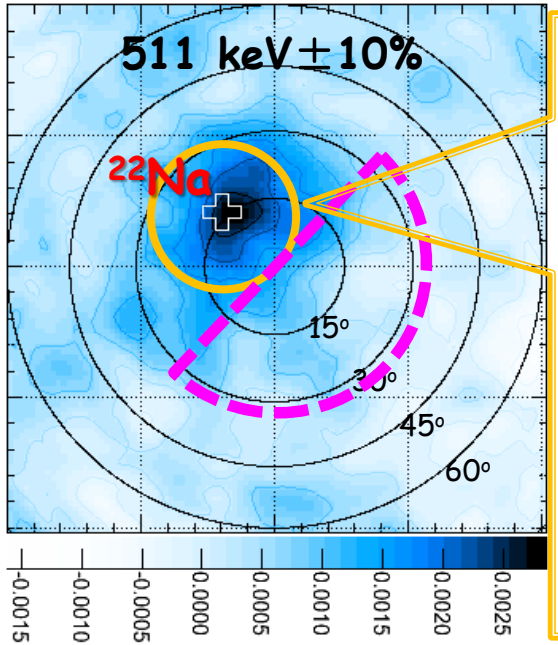
^{22}Na shielded by thin Pb

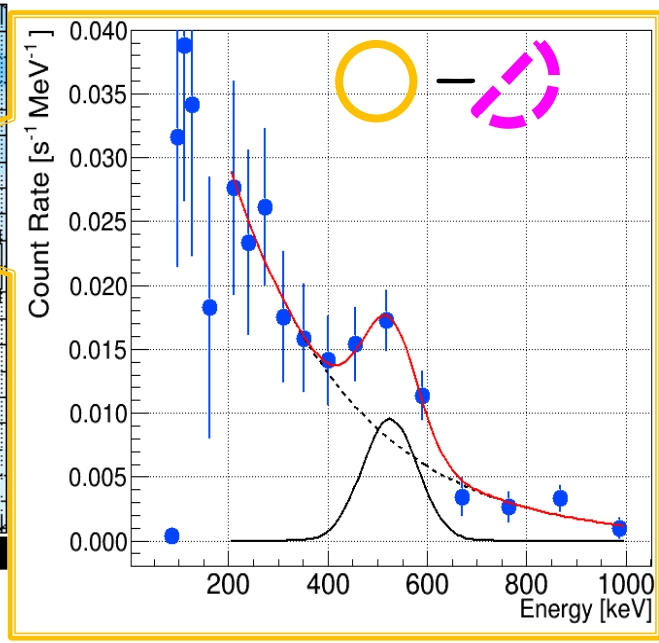
27 kBq equivalent

Dose by RI : ~0.0003 uSv/h
Space dose : 0.05-0.1 uSv/h
⇒ Source = 1/200-300 BG









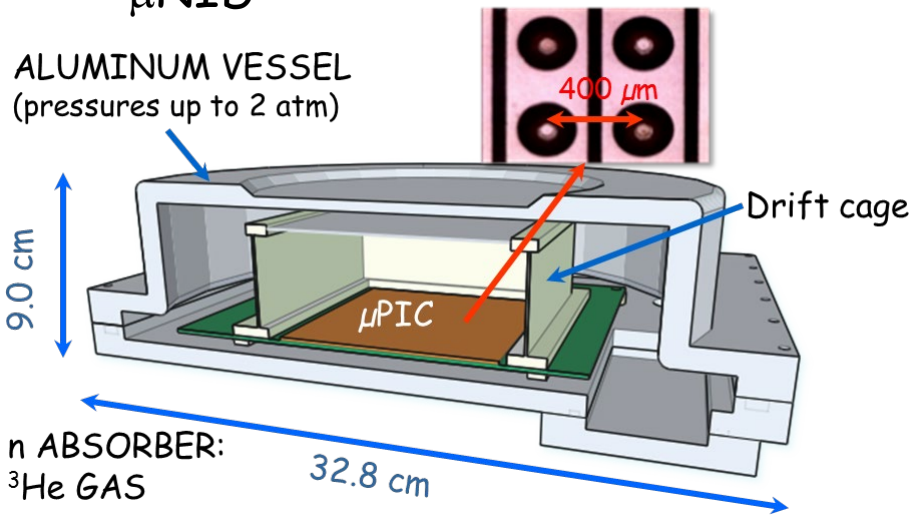
By imaging spectroscopy,
ETCC can detect a very weak source without any shield !

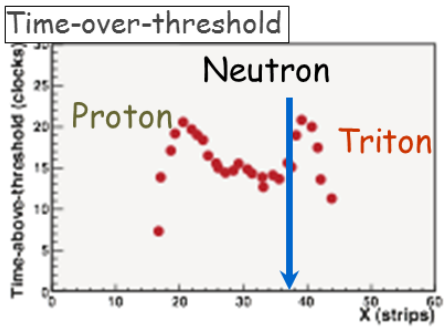
Other μ-PIC applications

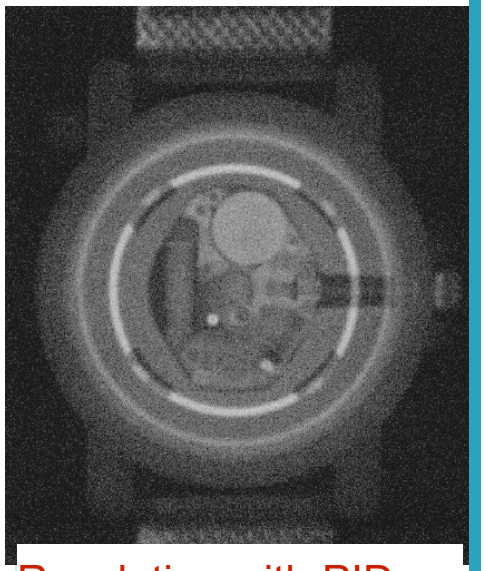
Neutron imaging

μNID

J. D. Parker+, NIM A (2013)







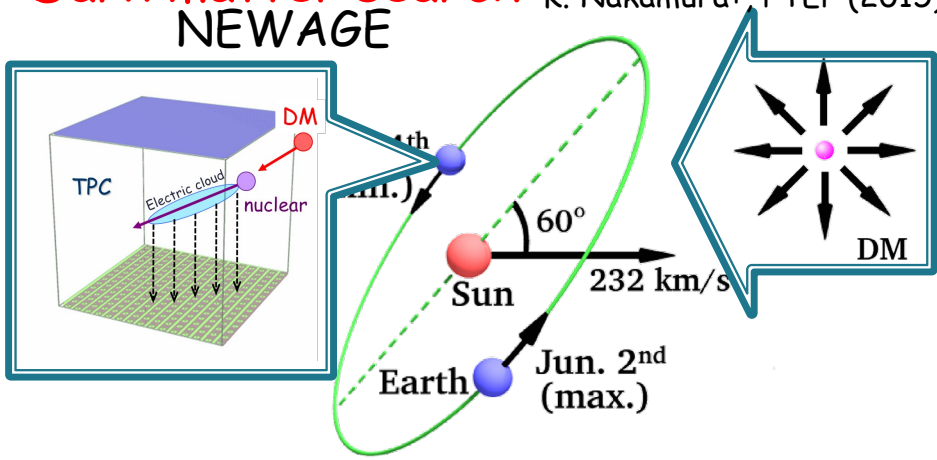
Resolution with PID:
105~130 μm(σ)

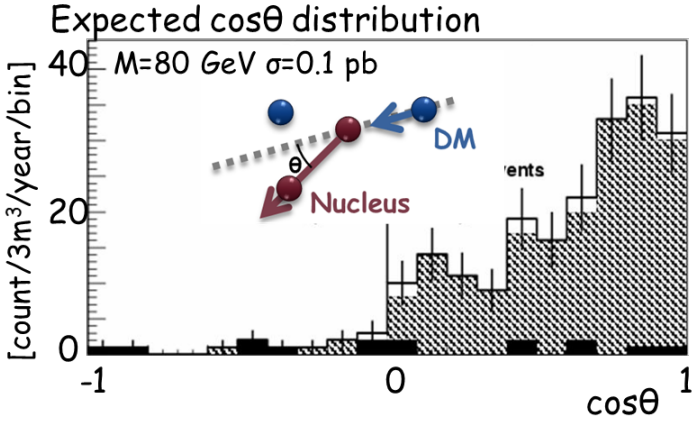
- ^{3}He + n -> p + ^{3}H
- Using template of ToT, we obtain neutron incident position

Dark matter search

NEWAGE

K. Miuchi+, PhL B (2007),
K. Nakamura+, PTEP (2015)





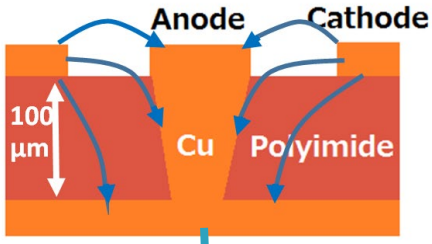
- Dark-matter scatters the nuclear of detector.
- Because a TPC can detect the angle θ between directions od DM-wind and recoil nuclear, we can detect the DM-wind by measurement of asymmetry of cos θ.

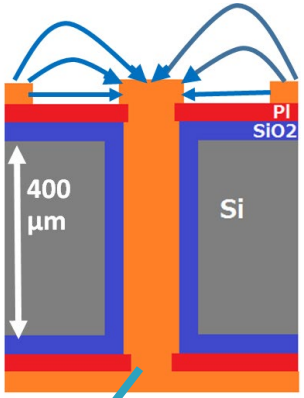
Development of new type μ-PIC

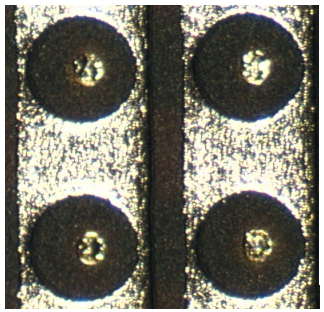
Requirements from applications:

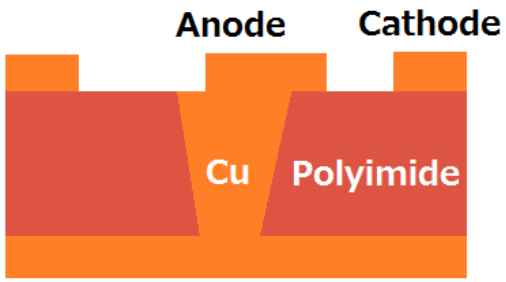
1. Higher gas gain
2. Suppression of discharge
3. Higher position resolution

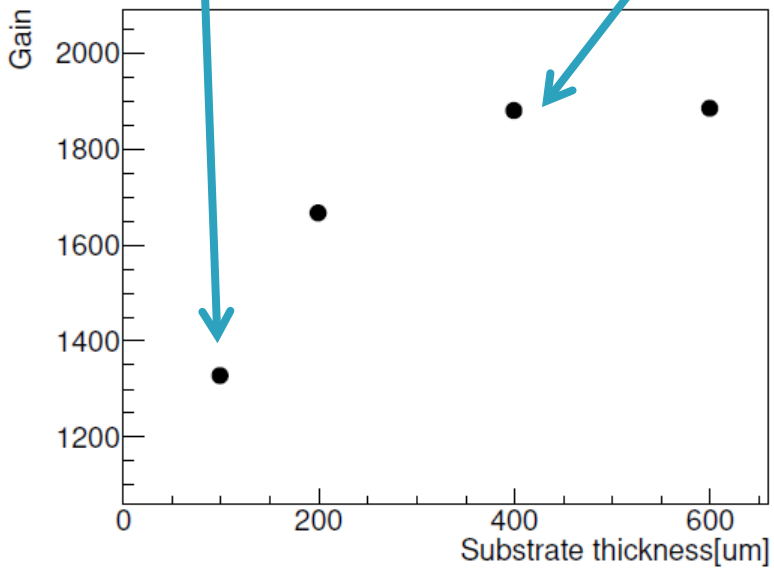
- Thick substrate
- Precise manufacturing
- Fine pitch











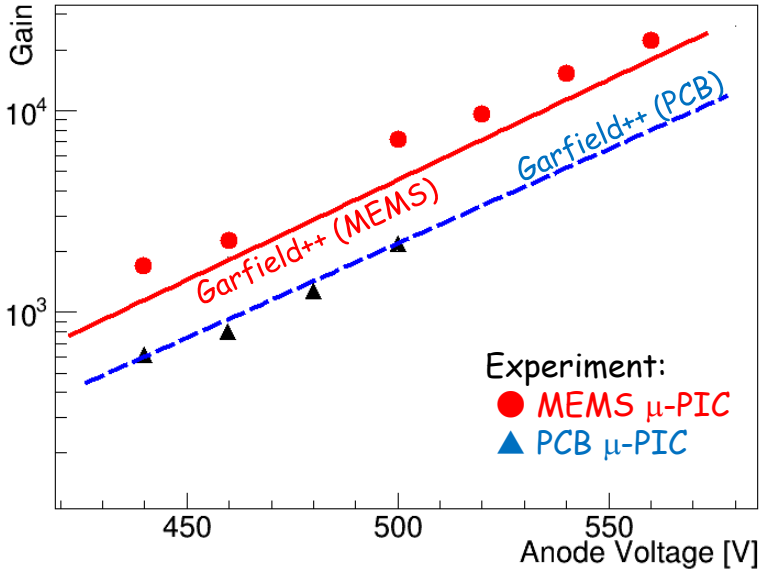
PCB technology :

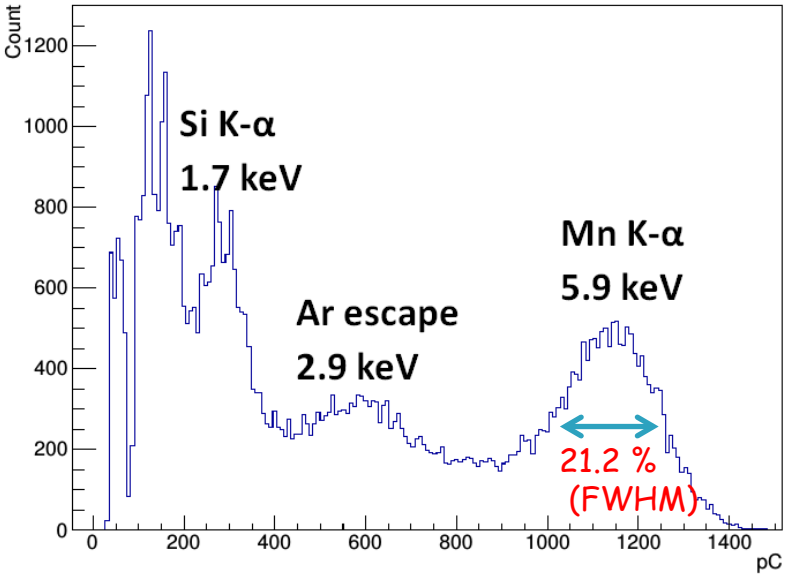
- Thicker substrate causes thicker anode
- Precision of manufacturing is ~10 μm
- Minimum of anode diameter is 50 μm
  -> Pixel pitch is limited by anode

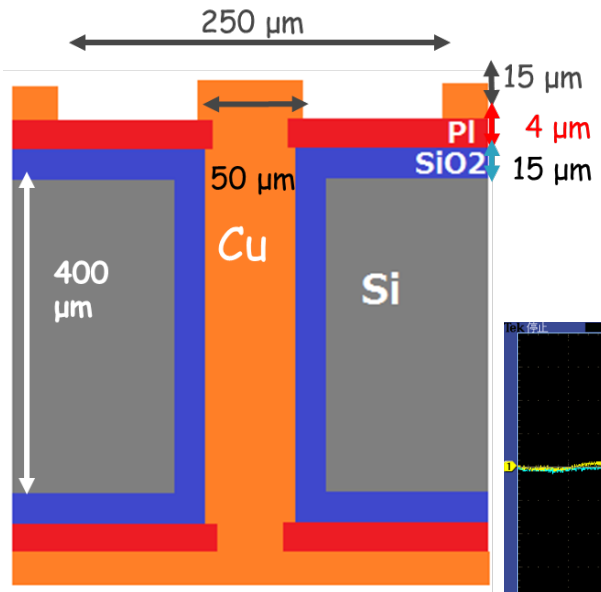
Micro Electro Mechanical Systems

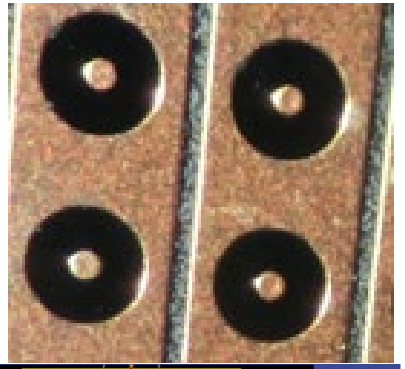
- MEMS technology can make deep through-hole keeping anode diameter
- Precision of manufacturing is a few μm

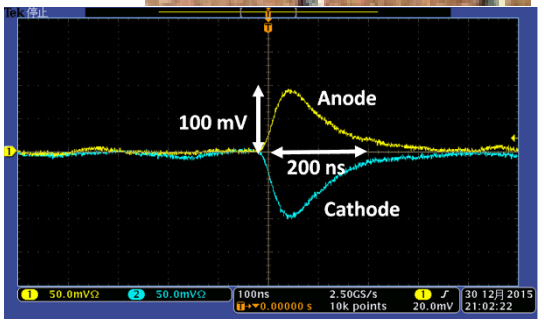
MEMS μ-PIC











- MEMS μ-PIC successfully detected X-ray.
- Large gain with stable operation :
  22000 (no discharge during 20 hours)
  15000 (no discharge over 300 hours)
- Good energy resolution :
  21.2% @ 5.89 keV (FWHM)
- Discharge rate of MEMS μ-PIC is less than that of PCB μ-PIC.

Performance of test production improved those of current detectors.
MEMS μ-PIC may become a next standard.

Summary

- Performance of PCB μ-PIC :
  - Large Detection area — 10x10, 30x30 cm^2
  - High gas gain — ~6000 (stable operation), 15000 (max)
  - Energy resolution — ~30% @ 5.89 keV (FWHM)
  - Fine position resolution — ~120 μm (RMS)
  - Good gain uniformity — < 5-7% (RMS, 100 cm^2)
- Applications of μ-PIC :
  - Electron-Tracking Compton Camera
    MeV gamma-ray astronomy, Medical imaging, Environmental monitoring
  - Neutron Imaging
  - Dark matter search
- Development of MEMS μ-PIC :
  - High gas gain — ~22000 during 20 hours
  - Stable operation — ~15000 over 300 hours
    Discharge rate is less than that of PCB type
  - Good energy resolution — 21.2% @ 5.89 keV (FWHM)